CHAPTER 5

Conclusions

The research study consists of 2 main parts: first, synthesis and characterization of vertically aligned ZnO nanowires by CVD process and second, fabrication and investigation of ethanol sensor device based on the vertically aligned ZnO nanowires. In this chapter, the overall conclusions will be presented with outline future perspective.

5.1 Synthesis and characterization of vertically aligned ZnO nanowires

The vertically aligned ZnO nanowires were synthesized on glass slide substrate of zinc acetate dihydrate seeding layer using chemical vapor deposition technique in acetone atmosphere. As mentioned in chapter 3, the interesting studied parameters were in terms of growth temperature and acetone flow rate. First, the growth temperature of prepared ZnO nanowires was varied between 400°C to 550°C. It was found that the diameter of ZnO nanowires increased as increasing growth temperature reaching the maximum diameter at the growth temperature of 500°C and then decreasing at above 500°C. As a result, it can be explained by the nuclei probability as shown in Eq. (2.14), $P_N = exp(-\Delta G_N^*/k_BT)$. The nuclei probability would raise up as the growth temperature increased affecting to the ZnO nuclei nearby agglomerate each other to form larger diameter.

ลิขสิทธิ์มหาวิทยาลัยเชียงใหม่
Copyright © by Chiang Mai University
All rights reserved

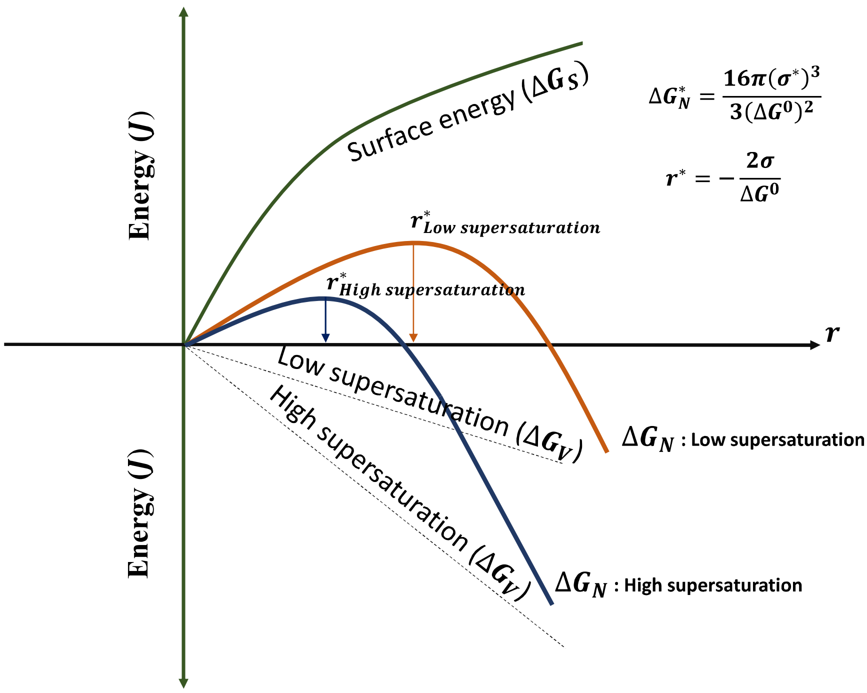

Figure 5.1: The effect of supersaturation ratio to critical radius of Zn nuclei at low supersaturation and high supersaturation

Next, beside the controlled growth temperature of the ZnO nanowires, the acetone flow rate was also altered from 5 sccm to 45 sccm. The results showed the diameter of ZnO nanowires decreased as increasing acetone flow rate. Resulting from the supersaturation ratio between partial pressure of oxygen in acetone atmosphere and in normal atmosphere, $s = \left(\frac{P_{O_2(vapor)}}{P_{O_2(standard)}}\right)$, the higher supersaturation ratio condition (s), the volume energy ($\varDelta G^0 = -RT \ln(s)$) that is the energy to create new morphology decreased. This will affect to easy and rapid growth of ZnO nanowires. In the other hand, the lower the supersaturation ratio condition, the growth of ZnO nanowires occured more difficult and slower. The different supersaturation ratio effects on diameters (r^*)of ZnO nanowires as shown in Figure 5.1.

ลิขสิทธิ์มหาวิทยาลัยเชียงใหม่
Copyright by Chiang Mai University
All rights reserved

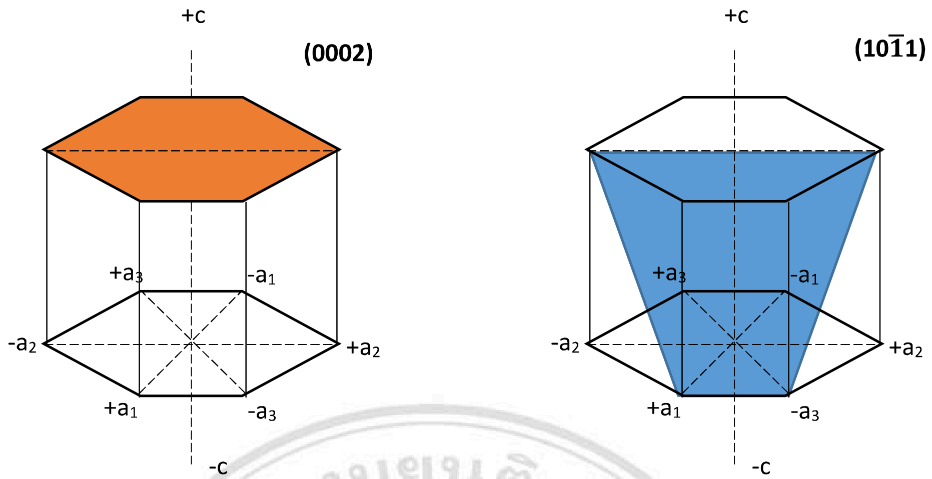

Figure 5.2: Illustration of hexagonol growth direction in (0002) and (10$\bar{1}$1)

Finally, the XRD analysis exhibited the wurtzite structure of ZnO with a dominant reflection peak of (0002), indicating the completely aligned on *c* axis as shown in Figure 5.1. The results of FE-SEM and XRD pattern of this study showed that the ZnO nanowires were aligned along the *c* axis which were consistent with the lowest surface free energy of the (0002) refection in wurtzite ZnO structure(1).

5.2 Fabrication and investigation of ethanol sensor device based on vertically aligned ZnO nanowires

One condition of the vertically aligned ZnO nanowires was fabricated as ethanol sensor and tested by ethanol concentration of 500 ppm at operating temperature in range of 350°C to 550°C. It was found that the highest sensitivity of ethanol sensor showed the optimal operating temperature at 500°C. Table 5.1 demonstrated the comparison of the optimal operating temperature in various morphologies based on ZnO. Moreover, at optimal operating temperature, the sensors revealed the short response and recovery time. Our result work achieve the good sensitivity of 30.08 compared with other work and operated at temperature 500°C

ลิขสิทธิ์มหาวิทยาลัยเชียงใหม่
Copyright© by Chiang Mai University
All rights reserved

Table 5.1: The optimal operating temperature of ZnO sensor with different morphologies

Morphology	Size	Temperature (°C)	Ethanol (ppm)	Sensor response
ZnO nanowires[33]	D : 90-220 nm	220	400	90
ZnO single crystal flakes[68]	W/T : 25-100	400	500	14.3
ZnO thinfilm[72]	G : 30±10 nm	60	500	1.85
ZnO nanopillar[52]	D : 10-30 nm	**	500	33
ZnO nanowires[53]	D : 80 nm,	300	500	43
ZnO thin film[25]	D : 250-750 nm	**	500	13.5
Flower-like ZnO[12]	D : 150 nm.	250	500	92
Zn : Al thin film[45]	G : 51-69 nm.	250	400	20
ZnO : In_2O_3nanofiber[8]	D : 10 nm	210	500	100
ZnO : Au[42]	D : 40-200 nm	300	500	222
Vertically aligned ZnO nanowires [This work]	D : 261	500	500	30.08

Symbol : D represents diameter, W represents width, T represents thickness, and G represents grain size.

5.3 Suggestion and future perspective

1. Indeep, CVD technique consists of 2 main sections as follows thermal oxidation process and deposition process; thermal oxidation occurs both of main section but primary thermal oxidation will also take place on growth area (400°C-550°C) and secondary thermal oxidation will happen between Zn source and O before deposition on growth area. Primary thermal oxidation, Zn acetate will be ionized by high temperature and reacted with O that diffuse into the Zn acetate surface boundary to form ZnO nuclei. Normally, the nuclei probability will be designed by temperature in Eq. (2.14). Briefly high growth temperature-high nuclei probability, it mean that high temperature, nuclei radius is colossal as nuclei fuse and agglomerate nearby nuclei. Thus, the size of ZnO nanowires is originated here. Secondary thermal oxidation, Zn source will react with O and transport to deposit on originated nuclei (Primary thermal oxidation). In process (Figure 5.3), you will see that the ZnO come from 2 process, that's so easy to growth and decreasing synthesis time. Thus, the growth temperature affecting seed layer should be prioritized as well. In our work, we overlook the growth temperature affecting seed layer (zinc acetate dihydrate) parameter but it should be considered. Interestingly on the top of ZnO nanowires at each conditions, the result showed different morphologies as seen by naked eye. It looks blunt on the top of ZnO. But at 450°C, it looks a blunt-pin at the same rate of heating down the growth temperature before ending CVD process. It may affect from growth

ลิขสิทธิ์มหาวิทยาลัยเชียงใหม่
Copyright© by Chiang Mai University
All rights reserved

temperature to seeding growth that we explained above. It was interesting point but it was elucidated unclearly.

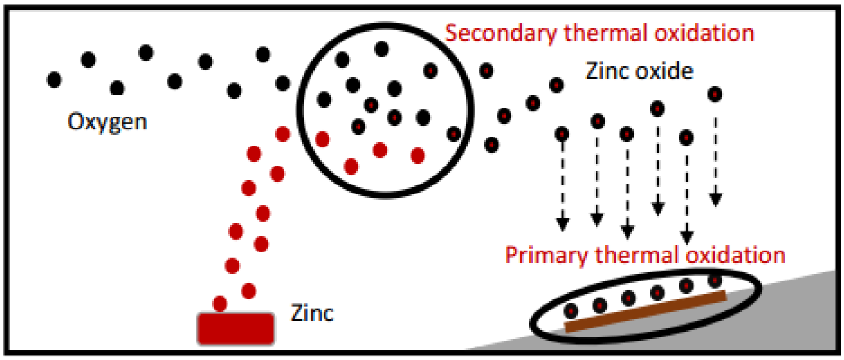

Figure 5.3: Schematic CVD process diagram of our opinion

2. The ethanol sensor based on ZnO nanowires should be studied from low operating temperature to higher temperature for preventing melt-substrate.

For the future perspective, the effect of growth temperature on seeding growth will be studied. The vertically aligned ZnO nanowires will be developed to be a more uniformity on the substrate and tested with different gas such as ammonia, formaldehyde and also acetone. Moreover, doping metal with ZnO nanowires will be applied for better gas response and.

ลิขสิทธิ์มหาวิทยาลัยเชียงใหม่
Copyright© by Chiang Mai University
All rights reserved